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VULNERABILITY OF HUMAN PERFORMANCE IN COMMUNICATIONS

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Brief

Research and theoretical speculations concerning the human link as one source of vulnerability in military communication systems is high-lighted. The following factors were concerned:

1. Characteristics of the message, including amount of information and readability.

2. The physical environment, with specific reference to noise, atmospheric and thermal conditions, and stress including isolation and confinement.

3. Characteristics of the human operator including sensory, perceptual and intellectual capacities; vigilance and susceptibility to fatigue; training and memory; social, motivational and personality factors; and psychopathology.

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Vulnerability of Human Performance in Communications

Introduction

A communications system may be described as consisting of five stages: source, transmitter, channel, receiver, and destination (Miller, 1951). Obviously, the ultimate source and destination of any message will be human beings. The three intermediate stages, however, may be represented either by a human or, more commonly, by a man-machine component. A human link, therefore, enters into each stage of the communications system. The characteristics of this human link impose limitations and sources of error upon the entire communication process. Many of these characteristics have been investigated by psychologists. It is the purpose of the present review to summarize the more salient research findings in relation to problems of vulnerability of military communications. Principal attention will be given to human performance in connection with the three intermediate components of the system: transmitter, channel, and receiver. Psychological factors associated with the source and destination of communications will be considered only insofar as they bear upon the intelligibility of the message.

Since there is considerable overlap among the intermediate components with respect to the basic psychological functions, needless repetition may be avoided by organizing the discussion around these psychological functions rather than around the components as such. The plan to be followed, then, will be to consider, in turn, performance factors stemming from each of three sources: (1) characteristics of the message; (2) the physical environment; and (3) the characteristics of the human operator. Admittedly, the classification of certain items with respect to this scheme may appear somewhat arbitrary; nevertheless it should serve well enough for purposes of organization.

1. Characteristics of the Message

Amount of Information

In communication theory the unit of information is called a "bit." Information here is used in its technical sense as referring to the occurrence of one out of a set of alternative stimuli; "amount of information" being expressed as the logarithm of the number of alternatives. It is customary to use logarithms to the base 2 for this purpose. Suppose, for example, a message consists of a series of unrelated letters and numbers, as in cipher code. Here, of course, there is no context to aid the receiver in

transcribing the message. From his standpoint, any one of the 26 letters and 10 numerals is as likely as any other to occur. Since $\log_2 36 = 5.17$, each character in the message carried 5.17 bits of information; this represents the number of correct decisions which must be made in order to determine which of the 36 possible characters was sent.

Morse code, whether in radio telegraphy or in "blinker" signaling, represents letters and numerals by combinations of two signals, a "long" and a "short". The average character in Morse contains 3.55 such signals, consequently, each signal of a message in cipher code carries on the average 5.17/3.55, or approximately 1.5 bits of information. Since there is no meaningful context, each bit of information is crucial to accurate reception of the message. As might be expected, the likelihood of confusing one Morse code letter with another has been shown to be closely related to their similarity (Rothkopf, 1957).

Considerations such as those just discussed raise important questions as to the capacities of the human organism to handle information of this type when it is coming in continuously at a fast rate. Various factors, both in the environment and in the organism, may operate singly and in interaction with one another, to affect these capacities, introducing gaps and/or errors into the message as received.

One obvious way to improve accuracy of reception is to repeat the message. In the language of information theory, this introduces "redundancy"—the redundant elements carry no new information. All languages are redundant, consequently plain-language communication, other things being equal, is less susceptible of error, especially in its reception, than cipher messages. Here, context as well as differences in the frequencies with which various words occur in ordinary language provide additional cues. But on the other hand, these same factors may also introduce new possibilities of error on the part of the human link in the communications system. For example, the "proofreader's illusion" is the failure to detect a spelling error in a familiar word. Errors of this type, too, must be considered.

Readability

It has been demonstrated repeatedly that plain-language communications may generate considerable confusion and misunderstanding, even though they are expressed in words which are themselves quite familiar and uncomplicated. Miller (1951, p. 132) gives the following example of a very difficult sentence, clothed in common words: "Unless you don't approve of saying no, you won't refuse." Since techniques are available (Flesch, 1948) for evaluating the "readability" of verbal communications, it is suggested that

still another source of error might be minimized by applying these techniques to certain types of military communication.

2. The Physical Environment

Noise

Communications engineers customarily use the term "noise" to designate any factor which introduces random error into a communications system. In this sense "noise" might consist of static or other auditory interference in a radio channel, "snow" in a television picture, a background of glare, flashing lights, drifting-patches of fog or smoke which interfere with the reception of blinker or semaphore signals, or redundant or otherwise irrelevant elements in the content of a message. Research directly relevant to communications problems has been done chiefly in connection with noise defined as "unwanted sound". This is summarized briefly below.

Noise in the last-mentioned sense may disturb communications: (1) by masking the signal, (2) by acting as a distractor to the operator, and (3) in some cases, by impairing the sensory acuity of the operator.

A considerable amount of research upon the masking of one sound by another has been published. Thus, it has been shown that low-frequency sounds tend to mask chiefly sounds of higher frequency; that random noise ("white noise") and speech have the most deleterious effect upon the reception of signals, whether code or speech; and that, in general, the signal-to-noise ratio in decibels is a more significant factor than the absolute intensities of either signal or noise in determining masking effects (Chapanis, Garner, & Morgan, 1949). Insofar as the masking noise arises from the communications equipment or the channel, the problem is one of equipment design. To the extent that the interference originates in the immediate surroundings of the operator, its control becomes a question of providing optimally favorable working conditions for the operator. The former problem has received a great deal of research attention; the latter, less. In view of the demonstrated significance of masking as a factor impairing the reception of messages, it seems likely that further systematic exploration of possibilities for improving the working environment in this respect might yield large dividends.

The effects upon performance of noise considered as a distractor are not too clearly defined. The experimental literature contains

many studies, the net results of which are somewhat ambiguous. Some investigators have reported slight improvements in the speed and/or accuracy of performance in various kinds of task; some have reported deterioration of performance; while others have found little change one way or the other. On the other hand, it has been shown that the introduction of noise is followed by an increase in energy expended upon perceptual-motor tasks of a routine character, but that continued exposure to moderate and fairly uniform noise leads rather quickly to adaptation on the subject's part and a return of energy expenditure to "normal" working levels (Harmon, 1933). This research, however, has not been carried out specifically in connection with communications problems. It might be worthwhile, to investigate the matter in a concrete situation of this type. In any case, the effects of noise as a masker of signals and as a distractor should be sharply distinguished.

Finally, it should be noted that long-time exposure to noise at higher levels of intensity tends to impair auditory acuity. This fact emphasizes the advisability of periodic retesting of communications personnel assigned to submarine duty, exposed to high intensity airplane noise, etc.

Other Environmental Conditions

Temperature, illumination, atmospheric conditions, the "purity" of the air, all have been shown to affect human performance in varying degrees under different circumstances. All must therefore be regarded as potential sources of error in communications. Unfortunately, little or nothing is known concerning their effects in this specific context. Since the human organism is adaptable to a fairly wide range of variation in conditions like these, such problems doubtless have not seemed particularly critical to communications workers in the past. But new developments place new and often excessive demands upon the adaptive capacities of the organism; demands which may call for further examination of factors like these in relation to communications problems. In this connection, recent studies of the extremely disruptive effects of isolation and sensory deprivation may be recalled. At this point, it is well to emphasize that not all men are affected to the same extent. Research is necessary to determine how to select and train men who will be able to perform their tasks in communication networks even when subjected to such environmental extremes. Which men can best continue their communications duties under the stressful Antarctic conditions in which some men tended to show symptoms of social withdrawal and loss of interest labelled the "Long-eye" (Rohrer, 1960)? What kinds of men can best sustain communications performance under the conditions of sustained confinement and psychophysiological stress in Polaris submarines? Which men can continue effective

communication duties when subjected to the radiation, confinement, and weightlessness of space travel? We do not know!

Stress

Reaction to stress constitutes another research area which has received considerable attention in recent years, but unfortunately not from the standpoint of communications. In spite of its apparent relevance, one can do little more than indicate certain types of stress situation which might be expected to add to the fallibility of the human link in any type of communications system. Foremost among such conditions, of course, would be the stress of cold and hot wars. To a lesser degree, any emergency which entailed danger, operating under an abnormal work load, or excessive pressure for speed and/or accuracy, would constitute a stress situation. Again, prolonged confinement, as in a submarine or a space capsule is known to generate considerable stress and anxiety in some individuals. The actual effects of all such factors should be explored as fully as possible in any general review of a military communications system's vulnerability.

It is necessary to focus on communications performance under the conditions of high stress that would characterize any future wide-scale warfare. While it is a truism that some degradation of human performance typically occurs under wartime stress (Grinker & Spiegel, 1945) we cannot at the present time specify with high accuracy which kinds of communication performance are most subject to such degradation and which individuals will be most subject to disruption of performance. Laboratory investigations have indicated, for example, that some individuals even improve in intellectual performance under conditions of stress (Atkinson, 1960, pp. 267-8). Further research is needed to determine just which aspects of performance in a communications network would be most likely to be disrupted, and which to be possibly facilitated by stress. Once such knowledge becomes available, suitable measures can be taken to reduce such disruption by proper selection, placement, and training of personnel as well as by changing equipments.

3. Characteristics of the Human Operator

At the present time prediction of performance in training programs (e.g., Class "A" School) is generally much more effective than prediction of later performance on the job under operational conditions (Kipnis & Glickman, 1958). Next to be discussed are some characteristics of the human operator which seem to have especially important implications for selection and training of personnel who will perform sucessfully in naval communications networks under operational conditions.

Sensory and Intellectual Capacities

It goes without saying that the operator, whatever his role in the communications system, must possess the requisite abilities to perform his task adequately under forseeable conditions. In view of the difference between plain-language and cipher communication, it may be pointed out that individuals appear to differ in their ability to learn meaningful and meaningless material. According to Miller (1951, p. 217) subjects who learn the one type of material most easily are not necessarily the ones who learn the other type best. Although correlations among performance measures within any one type of material are usually high, correlations between the two types are generally low: a fact which probably complicates the selection problem to an unrealized extent.

Attention also should be called to certain consequences of automation in all fields of activity including communications. As machines take over more and more of the routine tasks hitherto performed by man, the human operator is left increasing freedom and greater responsibility for the decision-making aspects of his task. At the same time, especially in military situations, he must be capable of taking over in cases of machine failure or destruction (as in combat). This perhaps calls for some upgrading of personnel as task requirements change. Certainly it underlines the need for periodic review and revision of selection criteria if the communications system is to maintain maximal reliability.

Perceptual Distortions

Beyond a doubt, this area comprises one of the most prolific sources of error as far as the human component in communications systems is concerned. The human link in the chain is particularly vulnerable here, for error tendencies, both in the transmission and the reception of messages, operate upon meaningful (plain language) and meaningless (cipher) material alike--although more strongly, it would appear, upon the former type of content. As usual, most of the available research deals, not with communication specifically, but with more general problems of the accuracy of perception. Campbell (1956) has recently reviewed the literature from the standpoint of communications systems.

Transient failure of the perceptual process, due to causes within or without the individual, may produce gaps in the message sent or received. Such gaps may be serious enough in themselves, but they are outweighed by another source of error which seems to be inherent in the perceptual (and memory) function

itself, the tendency to "structure" or organize information. Many leading principles of perceptual organization are known, and their effectiveness in inducing false or inaccurate perceptions has been demonstrated. Thus output, if imperfect, will tend to be "shorter, simpler, and less detailed than input" (Ibid, p. 342). It will tend to be unconsciously altered to conform to the expected message, to previous messages, to the attitudes of the receiver, and even to the desires attributed to the ultimate recipient of the message ("desire to please the receiver"). Inasmuch as tendencies like these have been shown to be significant determiners of perception in relatively neutral, laboratory situations, it would seem that their investigation as sources of error in communication should be of paramount importance.

Fatigue and Vigilance

The preceding discussion was concerned with psychological principles that determine the manner in which perceptual "gaps" will be filled in--often erroneously. But how do such gaps originate? Sometimes, of course, they arise from "noise" in the communications system itself, or from external distractions. Frequently they have their origin in fatigue effects, of which several varieties may be described. Thus, when an organism is subjected to a continuous and repetitive sensory input as, for example, in receiving Morse code which is being transmitted at a fairly rapid rate, "blocking" frequently occurs: the organism momentarily fails to receive or is unable to react to, the signal (Bills, 1931; 1935; Bills & McTeer, 1932).

Concerning the effects of fatigue in a more general sense, evidence bearing immediately upon the present problem is lacking. Generalizing from other research, however, it may be concluded tentatively that mild states of fatigue may actually facilitate performance to some extent by heightening vigilance; extreme fatigue, on the other hand, almost certainly would tend to disrupt performance. It has been shown, in fact, that for most activities there is an optimal level of vigilance, related apparently to the general level of neuromuscular tonus in the organism as a whole. Tonus levels either above or below these optima seem not to be conducive to most efficient functioning, but the matter has not been investigated in relation to communication problems.

There is one question concerning vigilance which has been attacked experimentally; the problem of attention to infrequent signals as, for example, when a radioman on watch must detect at long intervals an occasional call to his own ship among a multitude of other messages. The evidence from studies dealing

with such situations indicates that, under these conditions, vigilance tends to be lowered, with attendant likelihood that the crucial message will be missed, in its entirety or in part. Research has been performed on maintaining operator vigilance by filling in such blank intervals with some type of "dummy" message--additional research devoted to discovery of other methods of maintaining vigilance is in order.

Training

Glickman (1958), in a recent survey of personnel problems in the radioman rating, found that "the most crucial problems center about ability to receive code." Given reasonably adequate personnel selection procedures, this problem would seem to resolve itself largely into one of training. Questions as to the effectiveness of training in the Navy's Radioman Class "A" Schools and the adequacy and feasibility of performance standards that are required of trainees and candidates for advancement in rating, are being frequently and insistently raised. Research is in progress, but as yet no definitive answers to such questions have been forthcoming. The most recent review of literature in this area (Kurtz, 1959) describes various studies dealing with "practical" questions, like the comparative merits of different training methods, the standardization of achievement tests, and rate of progress in learning code, also some significant basic research into the psychological processes underlying learning and performance in this field. Until more such research data are available, however, it seems unlikely that attempts to improve this essential aspect of military communications will be attended by any very substantial degree of success.

One aspect of the training program which would seem to deserve more attention than it has received to date concerns the discrepancy between training (and testing) conditions in school on the one hand, and actual operational conditions for the reception of code messages on the other. For the most part, training and testing are conducted under relatively favorable conditions; yet operational conditions often are highly unfavorable, e.g., with respect to noise. Other factors disturbing communication also must be considered. For example, training should include experience with realistic conditions under which the enemy would attempt to interfere with our communications by "jamming" or inserting false messages and to acquire intelligence from our communications. It should be advantageous, therefore, especially during the later stages of training to increase duplication of operational conditions.

Memory

Two major problems are involved here. One concerns "short-term" memory for signals as they are continuously coming in and

being transformed into other symbols by the operator receiving the message. The other question concerns the long-term retention of code and other communications skills.

Short-term memory refers to the temporary storage of information for relatively immediate use. The problems which it raises are closely akin to those of immediate memory span, only here the situation is complicated by the rapid and continuous input of information. As far as communication is concerned, the short-term memory imposes certain limitations upon the man's capacity for processing information; it may also introduce various distortions like those mentioned in connection with perception, above. Kay (1960) has described some experiments illustrative of the limitations of short-term memory. He concludes that we do not yet have accurate knowledge of the extent of these limitations, nor what, if anything, can be done about them. The question has a very obvious bearing upon standards of speed and accuracy which can realistically be demanded in communications. Research here is lacking.

The second question, concerning the long-term retention of communication skills, is presently being investigated by the Naval Personnel Research Field Activity, Washington, D. C. One phase of this study has already been completed, and the results are now being analyzed; it deals with the loss of proficiency in receiving Morse code during the period between graduation from RM school and assignment to regular duty at receiving CW transmissions on an operational circuit. Since the interval between graduation and assignment may be fairly long drawn out, while the amount of intervening practice is subject to considerable individual variation, the problem of retention of skill becomes one of considerable significance. A second phase of the same research project contemplates a comparison of the effectiveness of several different retraining schedules in bringing RM school graduates back to an acceptable level of proficiency in receiving code.

Social, Motivational, and Personality Variables

Increasing use of man-machine systems seems to carry other implications for human communications performance. Increasing team-work within each such system is required. Such teamwork is obvious in, for example, the CIC, and NTDS systems, and in airplane crews, and should become increasingly important in the space age. Further research is needed to determine the relationships of social, motivational, and temperamental factors to human performance in such systems. We need to know, for instance, which individuals perform best in such communications systems as opposed to working alone. Which individuals can best tolerate the stress

involved in man-machine systems where communications are continually going back and forth between the different human, mechanical, and electronic elements?

Along these lines, one might speculate that as the human operator gives up routine, repetitive simple functions and concentrates on more complex ones, personality and social factors will become more and more important in selection and training. It is known, for example, that there is a wide range of individual differences in the extent to which humans can make successful decisions, Some people seem relatively unable to make decisions with any degree of rapidity; others do so impulsively, but with little accuracy or success. An instance which can be attributed, at least partially, to a failure in decision-making was widely reported in the mass media in January, 1961. In this case, the rising moon was classified as a ballistic missile by the early warning system and a short-lived "flap" resulted. Little, if anything is known today about the selection of individuals who can make appropriately rapid and correct decisions in complex man-machine systems under conditions of stress. Certainly this would seem to be a vulnerable point in communications.

Psychopathology

Another potentially disturbing factor is the probability that certain personnel with latent or even overt psychopathic tendencies will slip through our screening procedures or that personnel originally healthy will develop such tendencies under the stressful conditions that characterize warfare. Such psychopathy might well be manifested as hallucinated messages that enemy attack is underway, or should be forestalled by preventive war. Instances of sabotage of our own ships and equipment by psychopathic personnel are continually found, even under present conditions of relatively low stress and careful screening of personnel. Continual psychological revaluation of personnel in critical communications billets, of selection procedures, and of systems controls (like the "fail-safe" procedures) is required by the probability of eventualities such as those mentioned above.

Summary

The report represents a highlighting of research and theoretical speculations concerning the human link as one source of vulnerability in military communications systems. The factors considered were as follows:

1. Characteristics of the message, including amount of information and readability.

2. The physical environment, with specific reference to noise, atmospheric and thermal conditions, and stress including isolation and confinement.

3. Characteristics of the human operator including sensory, perceptual and intellectual capacities; vigilance and susceptibility to fatigue; training and memory; social, motivational and personality factors; and psychopathology.

These factors were considered in the context of selection and training of military communications personnel in the space age.

It is suggested that further study should include on the psychological side:

1. A program of basic research designed to answer certain crucial questions raised in this report, such as the determination of parameters in human decision-making, and performance in communications and information-processing systems.

2. Various applied research projects directed toward finding solutions to immediate practical problems of communication such as improved selection and training procedures for communications personnel.

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